BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: LM Launch Atmosphere Alternatives - Case 320

DATE: July 10, 1968

FROM: R. D. Raymond

ABSTRACT [redacted]

Factors of flammability, physiology, equipment and procedures affecting LM prelaunch atmosphere are evaluated. Flammability factors are dominant at launch and physiological factors become dominant a crew entry in flight. The capability to change the atmosphere between these periods is limited by equipment and crew procedures.

The conflicting requirements are not conclusively satisfied by any O_2/N_2 mixture at launch that is not changed before crew entry. Physiological requirements at crew entry are satisfied only with a high-oxygen-content atmosphere in the LM at launch (>80% O_2 or possibly >60% O_2) that will assure at least a sea level equivalent (around 70% O_2) when CM and LM atmospheres are mixed. Such high concentrations of O_2 have not been flammability tested in the LM at 14.7 psia, leaving an unassessed hazard. A low concentration of oxygen e.g., an air or nitrogen atmosphere, can control the fire risk but will require venting and repressurization before crew entry.

The penalty for venting the LM appears more acceptable than the potential fire risk. Venting capability can be added by modifying the LM relief valve latch, adding valve manual operation procedures and budgeting up to 6 more pounds of CM oxygen to repressurize the LM.

On the basis of this study the preferred solution is to provide LM venting and use a low-oxygen-content cabin atmosphere; e.g., nitrogen or air, for prelaunch. If this is not done and a high O_2 concentration is used at launch, the flammability risk should be assessed by testing at the maximum pressure experienced.

An alternative, if the hardware changes are unacceptable, is to use 60% O_2/40% N_2 without venting to zero pressure during boost. Even if valve settings and leakage are at their worst, this results in an equivalent air altitude of <2000 feet for the CM/LM, which can be reduced to sea level equivalent by purging for approximately 5 hours with 3.5 pounds of CM oxygen. The flammability risk of this mixture would also have to be assessed by test.

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SUBJECT: LM Launch Atmosphere Alternatives
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DATE: July 10, 1968

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MEMORANDUM FOR FILE

SUMMARY

Factors affecting the choice of the LM prelaunch atmosphere are evaluated. Significant factors are the potential flammability of the LM cabin at atmospheric pressure, physiological requirements at crew entry, system equipment and procedural capability, and the effect of LM venting into the SLA during ascent.

The major items affecting the choice of LM launch atmosphere are:

1. LM materials are selected for 6.2 psia 100% O_2, but configuration tests at sea level pressure have not been performed.

2. CM experience indicates flammability problems may occur at sea level pressure 100% O_2.

3. Some electrical ignition sources are present in the LM cabin during countdown.

4. Fire detection and extinguishment in a closed LM are difficult.

5. A LM fire could cause loss of the vehicle and will cause the crew to abandon the CM or abort from the pad.

6. The LM cabin atmosphere should be at a sea level equivalent, physiologically, at crew entry in flight.

7. Physiologically, a LM launch atmosphere of >80% O_2 is acceptable, 60% O_2 is marginal, and air or nitrogen are not acceptable unless changed in flight.

8. Procedures changes are necessary to allow use of

air or nitrogen on the pad and still obtain a sea level equivalent in flight.

9. An oxygen consumables penalty of 6 pounds might be required to allow LM atmosphere change in flight.

10. No launch atmosphere appears to satisfy both the physiological and flammability requirements. However, nitrogen or air used on the pad can be vented in flight and replaced by CM atmosphere to satisfy both of these requirements.

Flammability factors are dominant during prelaunch and ascent. LM cabin materials and configuration have been verified by test at 6.2 psia for in-space conditions with pure O_2 but have not been substantially tested for use in high O_2 concentration atmospheres at 14.7 psia. Electrical circuits energized during prelaunch and ascent provide some potential ignition sources. LM oxygen venting into the SLA during ascent reduces the protection of the nitrogen blanket provided to prevent possible fuel leak fires. These factors favor a low-oxygen-content atmosphere in the LM cabin at launch.

Physiological factors are dominant from the time of crew entry in flight. Based on requirements equivalent to those established for the CM atmosphere, at least a sea level equivalent alveoler oxygen pressure is needed, requiring 69% O_2 at 5 psia or possibly 77% O_2 at the lowest point of LM cabin pressure regulation (4.6 psia). Also, the suit loop integrity for egress mode operation must not be violated. These factors require either a high oxygen concentration at launch (possibly only >60% O_2 but more likely >80% O_2) or a LM venting and repressurization before crew entry.

Equipment capability and crew procedures can accommodate any O_2/N_2 mixture in the LM at launch with few changes. No changes are required to use a high oxygen content atmosphere (>80% O_2 and possibly >60% O_2). Lower O_2 concentrations at launch would require LM cabin venting in flight and possibly the use of an additional 6 pounds of CM oxygen to repressurize the LM. A relief valve modification might be required, depending on the method of venting. Changes to the relief valve and procedures appear minimal and are recommended to allow using a low-oxygen-content LM launch atmosphere.

Cabin launch atmosphere comparisons are discussed in a later section for 100% O_2, 60% O_2/40% N_2, air and 100% N_2. Physiologically 80%-100% O_2 is good without system change, while 60% O_2 or lower is marginal or unacceptable without venting or cabin leakage. With venting either air or nitrogen is a good choice since air is available in the cabin during countdown and nitrogen is available at the pad and flammability characteristecs of both are believed acceptable.

It is not conclusive that a mixture of O_2/N_2 can satisfy conflicting physiological and flammability requirements without equipment or crew procedure changes. Also, any high O_2 concentration atmosphere warrants more flammability testing. Therefore, it is preferable that the flammability risks be avoided and the physiological needs met by using a low O_2 concentration, e.g., in either air or N_2, as the LM cabin launch atmosphere and providing the necessary venting capability. If this is not acceptable, an alternate solution is to review physiological requirements with the goal of using about 60% O_2 and perform LM cabin configuration flammability tests at the highest pressure encountered.

FLAMMABILITY FACTORS

The impact of potential fires in the LM cabin or SLA on the selection of LM prelaunch atmosphere is evaluated in terms of combustible materials, ignition sources and fire control capability. If the fire risk for countdown through ascent is not acceptable with a high concentration of oxygen in the LM cabin, flammability considerations favor a minimum oxygen content at launch.

LM cabin nonmetallic materials have been carefully selected to inhibit fires. The materials selection process has verified the acceptability of the LM cabin materials and configuration for the flight environment by tests in an atmosphere of >95% O_2 at 6.2 psia (and 5.5 psia).[1] Some LM cabin materials and components were tested in pure O_2 at one-atmosphere but LM cabin configuration flammability tests were not performed. Therefore, an undetermined flammability risk still remains for the LM cabin with a high-oxygen-content atmosphere at 14.7 psia. This concern is substantiated by the CM cabin experience in that significant fires were encountered during BP1224 testing at 16.2 psia, >95% O_2, after passing tests at 6.2 psia in a >95% O_2 atmosphere. Changing the CM cabin atmosphere to 60% O_2/40% N_2 provided acceptable flammability characteristics. This history is especially significant in that the materials in the CM were chosen for the 100% O_2, 16.2 psia environment.

The major potential ignition sources in the LM cabin during countdown and ascent are electrical circuits. The number of possible ignition sources is low compared to in-space operation, however, because most electrical subsystems are inactive at launch. Active electrical circuits during countdown (after LM closeout at about T-13 hours) are the batteries and busses, descent electrical control assemblies, operational instrumentation, abort sensor assembly and inertial measurement unit. The status is similar at launch except the instrumentation is off and antenna heaters are on. Except for some displays, circuit breaker panels, cabin power wires to breaker panels, and switches, the active electrical units are outside of the LM cabin, reducing but not eliminating the ignition source hazard.

The potential ignition source hazard is not negligible now and might increase if mission planning flexibility requires more active circuits during countdown or launch. For example, LM-1 required development flight instrumentation (DFI) operation at launch and LM-3 might require a similar capability to obtain new data such as that required for evaluating launch vehicle induced oscillations.

The system fire control capability on the pad includes nitrogen purge to the SLA, freon extinguisher in the SLA, cabin temperature and pressure monitors, and (while in the SLA) external visual observation. The nitrogen purge inhibits SLA fires before launch and is incorporated primarily because of potential hydrogen fuel leaks from the launch vehicle. The SLA nitrogen could act to contain a LM fire. The effectiveness of the SLA nitrogen blanket will be reduced during ascent by LM cabin oxygen venting into the SLA.

The LM cabin temperature and pressure measurements monitored by ground equipment might be used to detect a cabin fire. However, the sensitivity of these measurements will not assure timely fire detection. Visual LM fire detection is inhibited by the SLA enclosure and the fact that the LM is not manned at launch. Even if fire detection is accomplished, fire fighting is difficult because of limited access through the SLA and into the LM. For example, the LM hatches are hinged inward and will be difficult to open against a positive pressure differential.

The LM fire control problems are tempered by the fact that the LM is not manned at launch. Crew safety is accomplished if adequate time is provided for CM escape by egress or LET abort. However, substantial risk of losing a mission and vehicle remains in event of a LM fire.

Current LM flammability factors indicate a potential for significant LM cabin fire risk during countdown and ascent. These fire hazards can be reduced by configuration changes, based on full-scale testing, lower LM atmosphere oxygen content at launch and/or increased fire detection capability. A substantial reduction in oxygen content is the most effective measure available for LM cabin fire prevention.

PHYSIOLOGICAL FACTORS

Composition of the LM atmosphere at crew entry in flight is dominated by physiological requirements. The LM cabin atmosphere physiological requirements are not specifically established but evaluation is proceeding based on the CM requirements.(2) No direct physiological demands are made on LM atmosphere from LM close-out on the pad until crew entry in flight because the LM is unmanned.

The physiological requirement for the CM is that the minimum steady-state oxygen partial pressure in the cabin shall provide at least sea level equivalent partial pressure alveolar oxygen, with excursions below this value to 4,000 feet altitude equivalent allowable if there is a return to sea level within 4 hours.(3) Sea level equivalent at nominal CM cabin pressure of 5 psia is 69% O_2, at minimum CM pressure of 4.8 psia it is 73% O_2, and at minimum LM pressure of 4.6 psia it is 77% O_2.(3,4)

At LM crew entry* nominal sea level equivalent requires 69% O_2 at 5 psia in the LM/CM mixture. As shown in the Atmosphere Comparisons section this equivalent is easily achieved using a 100% O_2 LM launch atmosphere and is marginally achieved using a 60% O_2/40% N_2 LM launch atmosphere. However, using either air or 100% N_2 at launch requires LM venting and repressurization before crew entry.

*The time of crew entry is mission dependent. Earliest entry times are approximately T+66 hours on lunar missions or T+42 hours on earth orbital mission (or T+23 hours for an alternate.)

The need to maintain the LM physiological requirements after LM entry can lead to choice of a high required oxygen content. For example, pressure can drop to 4.6 psia after LM and CM hatch closures, requiring at least 77% O_2 to maintain sea level equivalent. Also, the LM can depressurize, requiring closed suit loop operation and purging of the suit loop. These factors are not as time-critical as initial LM entry, however, and can possibly be accommodated by additional purging from the CM before hatch closure or by taking advantage of even a small LM leakage over a longer period of time.

SYSTEM CAPABILITIES

Equipment capability and crew procedures can accommodate either O_2 or 60% O_2/40% N_2 with no major procedural problems. However, for physiological reasons either air or N_2 should be vented from the LM prior to crew entry and the LM repressurized from CM supplies. Venting can be accomplished either during ascent or after the transposition-and-docking tunnel pressurization. Venting requires crew procedures (valve operations) and possibly a LM relief valve modification to enable latching it open from the tunnel side. The provisions for pressurizing or venting the LM and the assumptions affecting pressurization are described in Appendix A.

Repressurizing the LM after venting either requires significant time or depletes the CM gaseous O_2 supplies temporarily. The CM oxygen system can accommodate these requirements, but procedural optimization can minimize the time and consumables impact. The LM can be pressurized in about 5 minutes by using all of the available CM gaseous oxygen supply. Completely refilling the CM O_2 tanks from the cryogenic source then requires about 1 1/2 to 2 hours. However, since the CM O_2 tanks are refilled at an initial rate of 8-9 lbs/hr., a substantial quantity (3-4 lbs.) will be available in about half an hour if needed for emergencies, such as abort. If it is desired to repressurize the LM without significantly depleting the CM gaseous supply, about an hour is required to allow the cryogenic supply to replace most of the oxygen at about the rate it is used.

The major system consumables factor is the O_2 used from CM supplies for repressurizations of the LM. The quantity of O_2 used ranges from about 1 to 13 pounds, depending on the initial LM atmosphere and the number of repressurizations in the procedure selected, as shown in Table B-2, Appendix B. However, the comparative impacts on the CM O_2 budget of the alternatives are limited to the excesses over the amount normally budgeted for maximum allowable leakage. About 7 pounds of the 640 pounds of CM O_2 loaded are budgeted to allow for maximum LM leakage. Thus, the 13 pounds for worst case usage, with venting and leakage, constitutes a 6 pound weight penalty over the best consumables case, starting with 100% O_2.

Four atmosphere alternatives are compared in Table B-2 on the basis of cabin oxygen concentration as a function of mission time for several potential procedures. The vent procedure indicates various methods of achieving acceptable results before crew entry. If O_2 is used, no venting is required. If 60% O_2 is used, options available are not venting, venting from lift-off (by latching open the LM tunnel hatch relief valve), or venting between the first and second tunnel pressurization (by latching open the LM tunnel hatch relief valve during the first tunnel entry and operating the tunnel vent valve.) If either air or N_2 is used, venting is required.

ATMOSPHERE COMPARISONS

Atmosphere comparisons are made to determine the possibility of using various O_2/N_2 mixtures for LM cabin atmosphere at launch. Mixtures evaluated are 100% O_2, 60% O_2/40% N_2, air and 100% N_2.

The LM cabin orbit insertion conditions are the same as initial prelaunch composition at a pressure determined by the hatch relief valve. If the LM is vented, the pressure will be zero. Otherwise, the pressure will be 5.25 to 5.4 psia, the relief valve operating range. The LM pressure may reach a level as high as 5.8 psid during ascent, but the relief valve cannot maintain a pressure above 5.4 psia in space.

The LM cabin condition at first tunnel pressurization, at transfer and docking, is unchanged from prelaunch conditions without leakage or venting. If the LM is vented from lift-off, the first LM repressurization results in a composition of 84% O_2. This estimate is based on uniform mixing and 70% O_2 in the CM prior to tunnel pressurization, as described in Table B-2, Appendix B.

The LM cabin atmosphere composition at the time of second tunnel pressurization, in preparation for LM entry, is shown in Table B-2 for cases without leakage and with maximum specification leakage of 0.2 pounds per hour. The LM is assumed to leak to essentially zero psia for the maximum leakage case. However, to be conservative, the CM is not considered to have leaked or to have been enriched beyond the condition of 70% O_2 at 5 psia.

The final CM/LM composition is based on uniform mixing at the time of LM entry. If the initial LM atmosphere is 100% O_2 the final mixture contains 84% O_2 without venting. However, if any mixture is used and venting is accomplished, the final mixture contains 84%-91% O_2. If 60% O_2/40% N_2 is used initially, the final mixture contains 66%-84% O_2 without venting.

A more detailed examination of the resulting CM/LM atmosphere for an initial LM atmosphere of 60% O_2/40% N_2 is described in Appendix B. Cases examined include initial conditions in the CM of 70% O_2, 73% O_2 and sea level equivalent at a given pressure, allowing a comparison of several unfavorable conditions. The resulting mixtures contain 64%-68% O_2 at various pressures without leakage or venting. Results compared in Figure B-2 show all cases are very close to sea level equivalent. The 73% O_2 initial CM atmosphere case provides the most realistic worst case and results in 68% O_2 in the combined CM/LM atmosphere. At 5 psia this is physiologically equivalent to <500 feet altitude and at the lowest regulated CM/LM combined pressure of 4.8 psia is equivalent to <2000 feet altitude.

Cases considering LM and CM leakage are also shown in Figure B-2 for LM entry at 42 hours and 66 hours, the earth orbital and lunar mission entry times. Composition of the mixed atmosphere ranges from 68% to 85% for LM entry at 42 hours and from 68% to 90% for entry at 66 hours.

Sea level equivalent can be reached in the worst case (<2000 ft.) by purging the combined CM/LM with CM supplies for about 5 hours at a consumables cost of about 3.5 lbs. O_2.

CONCLUSIONS

It is not conclusive that the conflicting physiological and flammability requirements on LM prelaunch atmosphere oxygen content can be resolved by any specific O_2/N_2 mixture. The currently accepted minimum for physiological reasons is

80% O_2.[2] The lowest that might be acceptable physiologically, as indicated in this report, is 60% O_2. The maximum allowable oxygen content at launch has not been established by flammability test.

Considering the unresolved flammability problems and available procedural solutions, it seems unnecessarily hazardous to select a high oxygen content prelaunch pressurant for the LM cabin. Flammability factors are dominant on the pad at atmospheric pressure and should be countered by a low oxygen content atmosphere.

The hardware and procedural changes necessary to allow LM cabin venting in space appear minimal. The CM oxygen consumable penalty for venting the LM is small compared with the total available. Incorporation of venting provisions is recommended in order to allow use of a safer prelaunch pressurant, such as air or nitrogen. Air is convenient because it is used through the countdown leak check and requires no additional purging.

If the venting recommendation is unacceptable, it is recommended that the physiological requirements be reviewed with the goal of using a mixture of about 60% O_2/40% N_2. Additionally, LM configuration flammability tests should be performed at 14.7 psia if any reasonably high oxygen percentage is used at atmospheric pressure.

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REFERENCES

1. United States Government Memorandum PD5/M622-16.8, Minutes of LM Repressurization Meeting, Systems Engineering Division, MSC, Houston, Texas, April 8, 1968

2. NASA Letter PD-AC/L121-68, LM Cabin Atmosphere at Launch, Apollo Spacecraft Program Manager, MSC, Houston, Texas, January 25, 1968.

3. United States Government Memorandum DA-68-46 19/2B, Senior Flammability Review Board Meeting, January 13, 1968, DA/ Director of Medical Research and Operations, MSC, Houston, Texas, January 25, 1968.

4. Bottomley, T. A., Jr., Physiological Constraints for Air-on-the-Pad, TM 67-2031-4, Bellcomm, Inc., September 30, 1967.

APPENDIX A

Hardware Constraints on LM/Tunnel Pressurization

The LM is pressurized from the CM for initial crew transfer after CM-LM docking. The tunnel provisions for accomplishing this pressurization are indicated in Figure A-1.

To pressurize the LM and tunnel, the CM pressure equalization valve in the crew compartment forward hatch is manually operated. CM cabin gas then flows into the tunnel. When the tunnel pressure exceeds the LM cabin pressure the gas flows into the LM through the LM upper hatch seal, because the hatch is designed to be forced slightly open by a small differential pressure to permit pressurization. This design does not allow the tunnel to be pressurized without also pressurizing the LM unless the LM is already at a pressure higher than the tunnel.

The differential pressure gage in the CM enables the tunnel pressure to be monitored with the hatches closed. The LM tunnel vent valve provides the gage a reference pressure in one position and allows venting of the tunnel in another position. The gases vented from the tunnel escape to an outside unpressurized compartment in the CM upper deck area.

The LM pressure dump valve in the LM upper hatch is not normally used in the initial LM pressurization. It is opened, however, in the process of entering the LM to assure that the LM and tunnel pressures are equalized. The dump valve can be manually opened by a handle on the tunnel side to allow any excess pressure in the LM to bleed down into the tunnel. The dump valve includes an automatic differential pressure control that limits the internal pressure in the LM to a maximum of 5.25 to 5.4 psid. These features are duplicated in a dump valve in the LM forward hatch.

The gas for pressurizing the tunnel and LM comes from the CM cabin with replacement from the CM oxygen supplies. If initially only the tunnel needs to be pressurized, less than 0.5 pound of oxygen is used, ignoring leakage. If the LM also needs to be pressurized, the additional 6 to 7 pounds of oxygen can be rapidly supplied from the CM gaseous stores. However, this depletes the gaseous storage containers temporarily, until they are refilled from cryogenic supplies at a maximum rate of about 8 to 9 lbs/hr.

The level that the system can be pressurized to is dependent on various valves and regulators, listed here for reference:

1. CM cabin pressure regulator -- 5 $\pm$ 0.2 psia

2. CM cabin pressure relief valve -- 6 $^{+0.2}_{-0.4}$ psid

3. LM cabin pressure relief valve -- 5.25 to 5.4 psid

4. LM cabin pressure regulator -- 4.8 $\pm$ 0.2 psia

IN the initial LM/tunnel pressurization the resulting pressure will be primarily affected by the CM cabin pressure regulator and possibly the LM cabin relief valve, if there has been no LM leakage. If leakage has occurred the initial pressurization will depend on CM oxygen supply capacity and the CM cabin pressure regulator.

The allowable cabin leakage rates for the system at 5 psia in space are from zero up to the following maximum specification values:

1. CM -- 0.2 lbs/hr

2. LM -- 0.2 lbs/hr

3. Tunnel --0.1 lbs/hr

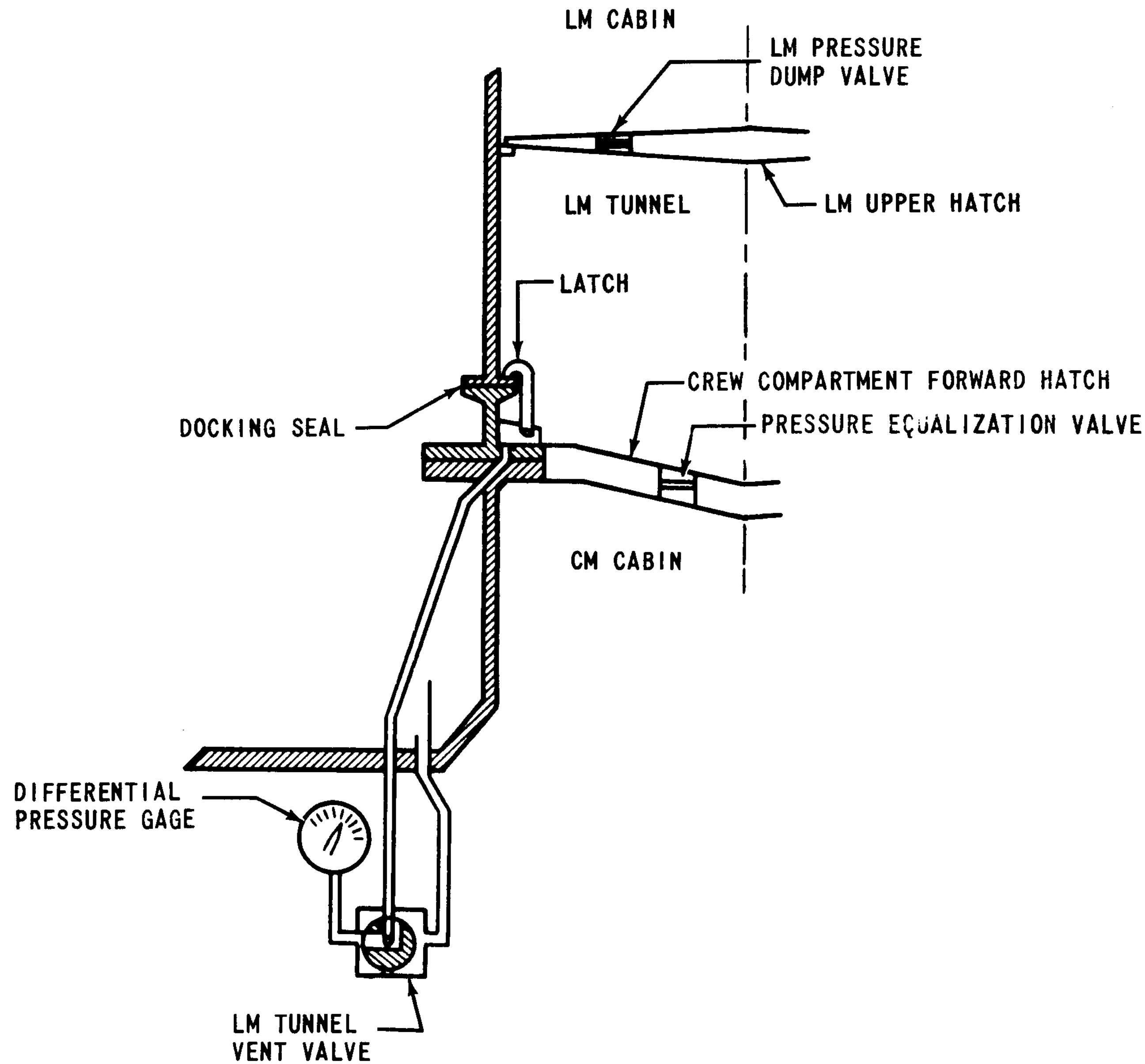

FIGURE A-1 - LM/TUNNEL PRESSURIZATION

APPENDIX B

Cabin Atmosphere Composition Estimates

The composition of the cabin atmosphere in the CM, the LM or the combined system when docked depends on several variables. Some of the variables are controlled while the others are not. The assumptions used in estimating cabin atmosphere compositions at specific times are described below:

The system capacity was estimated, as shown in Table B-1, by assuming that the gas density is the same as dry air at 20°C and that the free cabin volumes of the vehicles are:

1. CM -- 316 cu. ft.

2. LM -- 235 cu. ft.

3. Tunnel -- 11.5 cu. ft.

The LM cabin atmosphere at launch is assumed to be either 100% O_2, 60% O_2/40% N_2, air or 100% N_2. The LM atmosphere composition does not change until after docking (when the CM can be used to repressurize the LM) because the LM environmental control system is turned off. The LM cabin pressure decreases during launch to a maximum of 5.25 to 5.4 psia and can then either remain constant or decrease at a rate determined by leakage. The maximum leakage is assumed to be the maximum specification allowable of 0.2 lbs/hr at 5 psia in space.

The CM cabin atmosphere at launch is assumed to be 60% O_2/40% N_2. The planned procedure for controlling the CM atmosphere uses the waste management system as a controlled leak and requires the CM to reach at least a sea level equivalent cabin atmosphere composition within nominally 4 hours and not more than 8 hours after launch. At the nominal CM cabin pressure of 5.0 psia, sea level equivalent is 69% O_2/31% N_2 while at 4.8 psia it is 73% O_2 and at 5.2 psia it is about 65% O_2.

In determining the system atmosphere composition after docking and mixing the CM and LM atmospheres, it is assumed that the worst case (i.e., the lowest oxygen percentage at a given pressure) is obtained when no LM leakage occurs. This is illustrated by Figure B-1 by showing that the amount of N_2 remaining in the system to dilute the O_2 is constant at the initial conditions assumed with no leakage. However, when leakage is assumed the nitrogen in the LM or CM decays exponentially as a function of the remaining partial pressure of N_2, as shown for the maximum leak rate of 0.2 lbs/hr at 5 psia. Therefore, only for a case considering leakage is the time of mixing an important factor.

The resulting mixtures for the assumed initial atmospheres in LM are compared in Table B-2. The CM atmosphere at the time of mixing is assumed to be 70% O_2/30% N_2 at 5 psia, which is worse than a realistic nominal case since the CM is expected to be enriched to at least 73% to assure a sea level equivalent at the minimum regulation pressure of 4.8 psia.

In Table B-2 cases are considered for venting or not venting the LM, as applicable. Also, comparisons are shown for no LM leakage and maximum LM leakage. The venting indicated assumes a capability to manually control the LM dump valve, which in some cases requires a modification.

In order to obtain reasonable values of oxygen in the final mixtures, it is necessary to vent if air or nitrogen is used in the LM, as shown in Table B-2. However, if 100% oxygen is used venting becomes unnecessary. If a mixture of 60% O_2/40% N_2 is used in the LM, venting might be required to assure that the physiological needs are met. This decision needs additional definition of physiological requirements.

A closer look at the mixtures expected if the initial LM atmosphere is 60% O_2/40% N_2 is summarized in Tables B-3, B-4 and B-5. The worst cases (no leakage in LM or CM) are shown for different CM initial conditions within the pressure regulation limits. Table B-3 provides an arbitrary reference, assuming that the CM atmosphere is 70% O_2/30% N_2. Table B-4 assumes a more realistic CM atmosphere of at least 73% O_2, which provides a sea level equivalent or better for the complete regulation range of CM pressure. Table B-4 assumes a lower bound on CM atmosphere of sea level equivalent at the indicated CM pressure.

The range of combined CM/LM atmosphere compositions for the conditions assumed in Tables B-3, B-4 and B-5 are shown graphically in Figure B-2. The final mixtures are all close to sea level equivalent, even though no LM leakage is included. In particular, if the CM initial condition assumes 73% O_2, the resulting mixture is essentially sea level equivalent at the time of CM-LM mixing. For comparison, it is shown on Figure B-2 that when the maximum allowable leakage of 0.2 lbs/hr in the CM and LM is assumed, the resulting mixture at the time of LM entry is about 85% O_2 on earth orbital missions (T+42 hours) or about 90% O_2 on lunar missions (T+66 hours).

TABLE B-1. CABIN ATMOSPHERE CAPACITIES

PRESSURE PSIA	GAS DENSITY LBS/CU. FT.	GAS WEIGHT - LBS.			
		CM	LM	TUNNEL	TOTAL
14.7	0.075	23.7	17.6	0.86	42.2
5.4	0.0275	8.7	6.45	0.36	15.5
5.2	0.0264	8.35	6.2	0.3	14.9
5.0	0.0255	8.05	6.0	0.29	14.4
4.8	0.0245	7.75	5.75	0.28	13.8

TABLE B-2

LM ATMOSPHERE SELECTION MIXTURE COMPARISONS

INITIAL LM ATMOSPHERE	VENT PROCEDURE	LM ATMOSPHERE AT ORBIT INSERTION	LM ATMOSPHERE AFTER T/D AND TUNNEL PRESSURIZATION	LM ATMOSPHERE AFTER SECOND TUNNEL PRESSURIZATION: NO LM LEAK	LM ATMOSPHERE AFTER SECOND TUNNEL PRESSURIZATION: MAX. LM LEAK	CM/LM MIXED (NO CM LEAK)	CM O_2 USED* (LBS)
O_2	NO VENT	<5.4 PSIA 100% O_2	<5.4 PSIA 100% O_2	5 PSIA 100% O_2		84% O_2	0.5 TO 7
					5 PSIA 84% O_2		
60% O_2 40% N_2	NO VENT	<5.4 PSIA 60% O_2	<5.4 PSIA 60% O_2	5 PSIA 60% O_2		66% O_2	0.5 TO 7
					5 PSIA 84% O_2	84% O_2	
	VENT FROM LIFT-OFF	0 PSIA	5 PSIA 84% O_2	5 PSIA 84% O_2		84% O_2	7 TO 13
					5 PSIA 91% O_2	91% O_2	
	VENT AFTER FIRST TUNNEL PRESSURIZE	<5.4 PSIA 60% O_2	<5.4 PSIA 60% O_2	(VENT AND FILL) 5 PSIA 84% O_2		5 PSIA 84% O_2	7.5
AIR OR N_2	VENT FROM LIFT-OFF	0 PSIA	5 PSIA 84% O_2	5 PSIA 84% O_2		84%	7 TO 13
					5 PSIA 91% O_2	91%	
	VENT AFTER FIRST TUNNEL PRESSURIZE	<5.4 PSIA 21% O_2 OR 0% O_2	<5.4 PSIA 21% O_2 OR 0% O_2	(VENT AND FILL) 5 PSIA 84% O_2		5 PSIA 84% O_2	7.5

*7 lbs. is now budgeted to make up for LM leakage at the time of manning.

TABLE B-3

COMBINED CM/LM ATMOSPHERE WITHOUT LEAKAGE

INITIAL CM ATMOSPHERE		INITIAL LM ATMOSPHERE		COMBINED CM/LM ATMOSPHERE INCLUDING 0.3 LB O_2 FOR TUNNEL		
TOTAL CM GAS	CM N_2	TOTAL LM GAS	LM N_2	TOTAL CM/LM GAS	TOTAL CM/LM N_2	COMBINED COMPOSITION
4.8 PSIA 70% O_2 30% N_2 7.75 LBS	2.3 LBS	5.4 PSIA 60% O_2 40% N_2 6.45 LBS	2.6 LBS	14.5 LBS	4.9 LBS	5.03 PSIA 66% O_2 34% N_2
		5.25 PSIA 60% O_2 40% N_2 6.2 LBS	2.5 LBS	14.2 LBS	4.8 LBS	4.9 PSIA 66% O_2 34% N_2
5.0 PSIA 70% O_2 30% N_2 8.05 LBS	2.4 LBS	5.4 PSIA 60% O_2 40% N_2 6.45 LBS	2.6 LBS	14.8 LBS	5.0 LBS	5.16 PSIA 66% O_2 34% N_2
		5.25 PSIA 60% O_2 40% N_2 6.2 LBS	2.5 LBS	14.6 LBS	4.9 LBS	5.07 PSIA 66% O_2 34% N_2
5.2 PSIA 70% O_2 30% N_2 8.35 LBS	2.5 LBS	5.4 PSIA 60% O_2 40% N_2 6.45 LBS	2.6 LBS	15.1 LBS	5.1 LBS	5.25 PSIA 67% O_2 33% N_2
		5.25 PSIA 60% O_2 40% N_2 6.2 LBS	2.5 LBS	14.9 LBS	5.0 LBS	5.17 PSIA 67% O_2 33% N_2

TABLE B-4

COMBINED CM/LM ATMOSPHERE WITHOUT LEAKAGE

INITIAL CM ATMOSPHERE		INITIAL LM ATMOSPHERE		COMBINED CM/LM ATMOSPHERE INCLUDING 0.3 LB O_2 FOR TUNNEL		
TOTAL CM GAS	CM N_2	TOTAL LM GAS	LM N_2	TOTAL CM/LM GAS	TOTAL CM/LM N_2	COMBINED COMPOSITION
4.8 PSIA 73% O_2 27% N_2 7.75 LBS	2.1 LBS	5.4 PSIA 60% O_2 40% N_2 6.45 LBS	2.6 LBS	14.5 LBS	4.7 LBS	5.03 PSIA 68% O_2 32% N_2
		5.25 PSIA 60% O_2 40% N_2 6.2 LBS	2.5 LBS	14.2 LBS	4.6 LBS	4.9 PSIA 68% O_2 32% N_2
5.0 PSIA 73% O_2 27% N_2 8.05 LBS	2.2 LBS	5.4 PSIA 60% O_2 40% N_2 6.45 LBS	2.6 LBS	14.8 LBS	4.8 LBS	5.16 PSIA 68% O_2 32% N_2
		5.25 PSIA 60% O_2 40% N_2 6.2 LBS	2.5 LBS	14.6 LBS	4.7 LBS	5.07 PSIA 68% O_2 32% N_2
5.2 PSIA 73% O_2 27% N_2 8.35 LBS	2.3 LBS	5.4 PSIA 60% O_2 40% N_2 6.45 LBS	2.6 LBS	15.1 LBS	4.9 LBS	5.25 PSIA 68% O_2 32% N_2
		5.25 PSIA 60% O_2 40% N_2 6.2 LBS	2.5 LBS	14.9 LBS	4.8 LBS	5.17 PSIA 68% O_2 32% N_2

TABLE B-5

COMBINED CM/LM ATMOSPHERE WITHOUT LEAKAGE

INITIAL CM ATMOSPHERE		INITIAL LM ATMOSPHERE		COMBINED CM/LM ATMOSPHERE INCLUDING 0.3 LB O_2 FOR TUNNEL		
TOTAL CM GAS	CM N_2	TOTAL LM GAS	LM N_2	TOTAL CM/LM GAS	TOTAL CM/LM N_2	COMBINED COMPOSITION
4.8 PSIA 73% O_2 27% N_2 7.75 LBS	2.1 LBS	5.4 PSIA 60% O_2 40% N_2 6.45 LBS	2.6 LBS	14.5 LBS	4.7 LBS	5.03 PSIA 68% O_2 32% N_2
		5.25 PSIA 60% O_2 40% N_2 6.2 LBS	2.5 LBS	14.2 LBS	4.6 LBS	4.9 PSIA 68% O_2 32% N_2
5.0 PSIA 69% O_2 31% N_2 8.05 LBS	2.5 LBS	5.4 PSIA 60% O_2 40% N_2 6.45 LBS	2.6 LBS	14.8 LBS	5.1 LBS	5.16 PSIA 66% O_2 34% N_2
		5.25 PSIA 60% O_2 40% N_2 6.2 LBS	2.5 LBS	14.6 LBS	5.0 LBS	5.07 PSIA 66% O_2 34% N_2
5.2 PSIA 65% O_2 35% N_2 8.35 LBS	2.9 LBS	5.4 PSIA 60% O_2 40% N_2 6.45 LBS	2.6 LBS	15.1 LBS	5.5 LBS	5.25 PSIA 64% O_2 36% N_2
		5.25 PSIA 60% O_2 40% N_2 6.2 LBS	2.5 LBS	14.9 LBS	5.4 LBS	5.17 PSIA 64% O_2 36% N_2

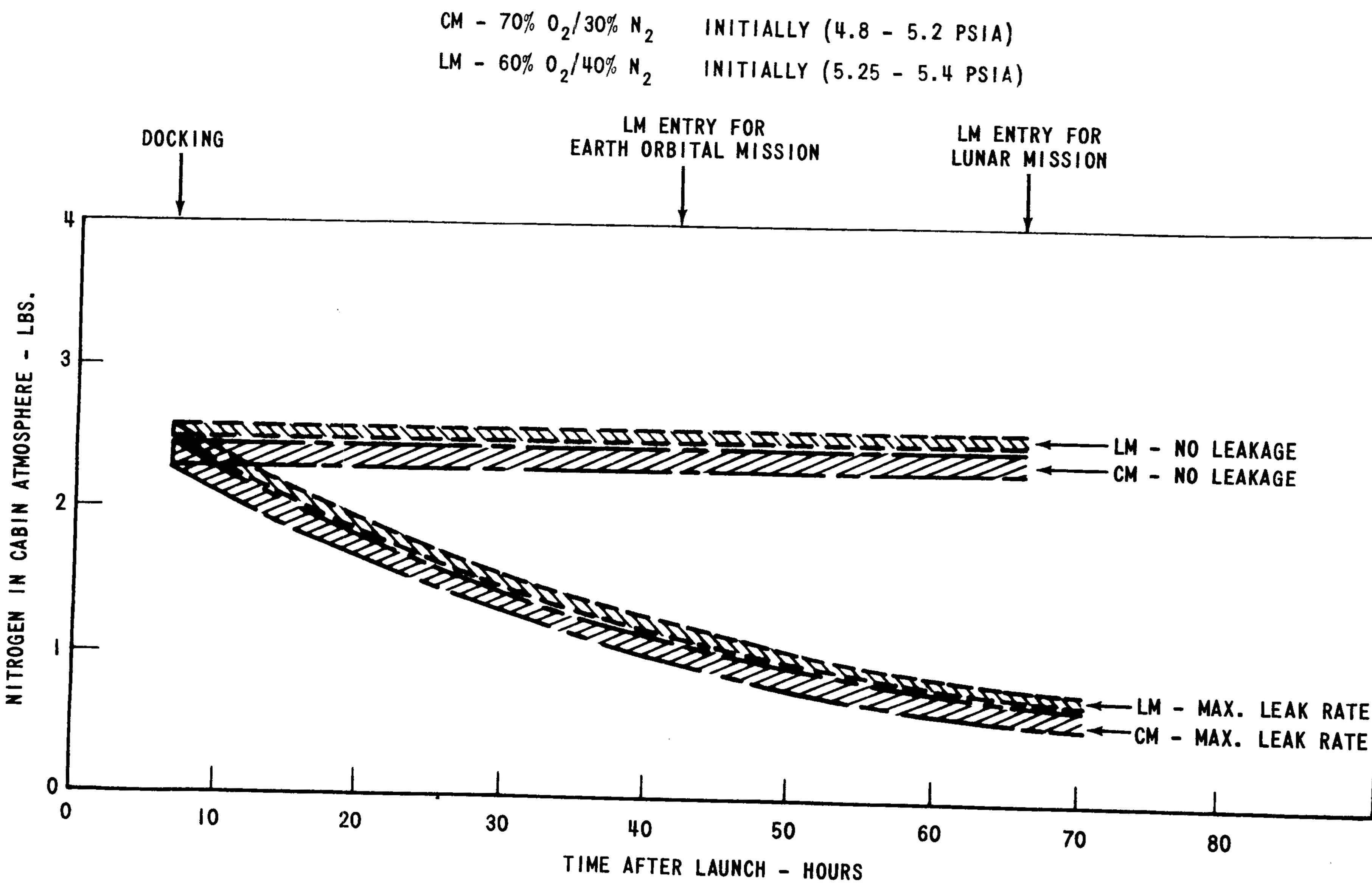

FIGURE B-1 - CM AND LM NITROGEN REMAINING AT TIME OF COMBINING FOR LM ENTRY

1. INITIAL LM ATMOSPHERE IN EACH CASE - 60% O_2/40% N_2, 5.25-5.4 PSIA

2. INITIAL CM ATMOSPHERE - VARIED COMPOSITION, 4.8-5.2 PSIA
   - CASE A., 70% O_2/30% N_2
   - CASE B., 73% O_2/27% N_2
   - CASE C., SEA LEVEL EQUIVALENT
   - CASE D. AND E., 70% O_2/30% N_2

3. NO LEAKAGE IN CASES A., B., AND C.; MAXIMUM ALLOWABLE LEAKAGE OF 0.2 LBS/HR. IN CASES D. AND E. (IN THE LM AND THE CM).

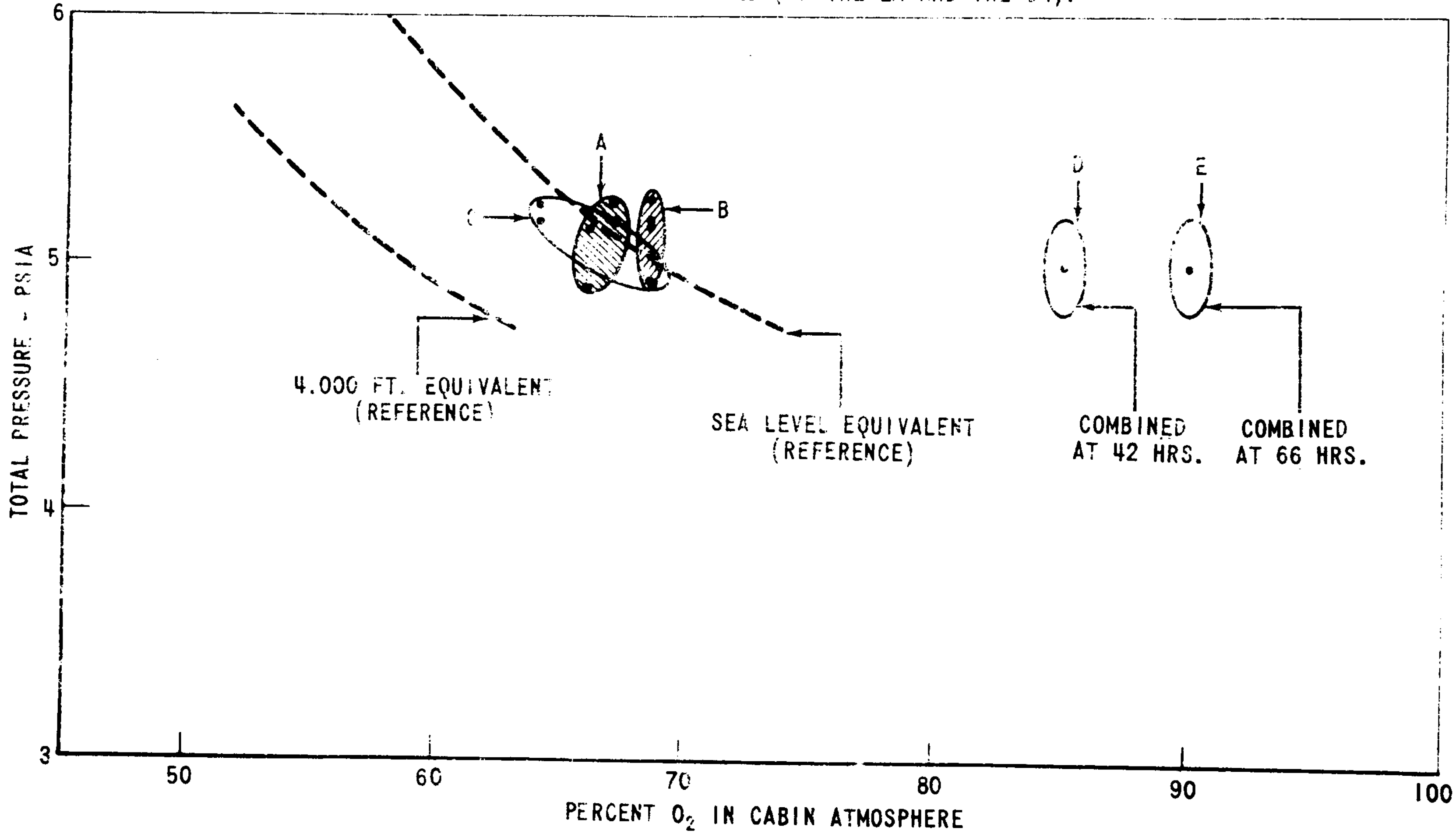

FIGURE B-2 - COMBINED CM AND LM ATMOSPHERE - RESULTING % O_2 AND TOTAL PRESSURE

BELLCOMM, INC.

SUBJECT: LM Launch Atmosphere Alternatives Case 320

FROM: R. D. Raymond

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